UpTempO buoys for Understanding and Prediction

Michael Steele
Applied Physics Laboratory, University of Washington, 1013 NE 40th St, Seattle, WA 98105
phone: (206) 543-6586 fax: (206) 616-3142 email: mas@apl.washington.edu

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MAJOR GOALS

Our long-term goal was to better understand the evolution of heat content in the upper Arctic Ocean within the Seasonal Ice Zone (**SIZ**), both seasonally during summer warming and fall cooling, and interannually as sea ice retreats and the warming season lengthens. The effort was a contribution to the multi-investigator ONR-sponsored **SIZRS** project (SIZ Reconnaissance Surveys).

Our main objectives were to:

(1) Develop the capability to observe upper ocean warming and cooling using air-deployed ocean drifting buoys.
(2) Better understand the time and space scales of summer warming in the SIZ.
(3) Investigate the relationships between sea ice retreat and upper ocean warming.

ACCOMPLISHED

<u>I. Buoy deployments and data</u>:

We worked with the Pacific Gyre (PG) buoy company (Oceanside, CA) to re-start an air-drop buoy capability that had grown dormant over the past several years. This program was initiated by Professor Peter Niiler at Scripps (UCSD) to drop 200 m long thermistor string buoys ahead of hurricanes in the Gulf of Mexico via Air Force C130 planes, the so-called “hurricane hunters.” In recent years, a surplus of buoys developed which coincided with a lack of technological updating. Thus our approach was to work with PG to develop a state-of-the-art air-drop buoy for polar applications. At the same time, we worked with the US Coast Guard (USCG) to deploy these buoys from the Alaskan USCG C130 planes based out of Kodiak, Alaska as part of the SIZRS program.

All SIZRS air-deployed UpTempO buoys have a surface hull with sensors for (i) surface air pressure, (ii) sea surface temperature, and (iii) submergence detection. The hull also contains alkaline batteries, Iridium and GPS antennae, and electronics. Below the hull hangs a 25 m or 60 m string of temperature and ocean pressure sensors, and a CT cell at 4 m depth. Some have an anemometer to measure surface wind speed and direction.

Coast Guard approval to deploy by air was finalized in late spring 2013. ONR funding to deploy buoys expired before the 2016 field season. Thus SIZRS activity during 2013-2015 was as follows: <u>2013</u>: One buoy deployed by air, three by ship; <u>2014 & 2015</u>: Four buoys deployed by air in each year.

SIZRS buoys are typically deployed in challenging environments, i.e., in mixed ice/open water conditions. We experienced some technical difficulties in the first two years with regard to design (epoxy leakages, sensor string malfunctions) but by 2015 we had good success in measuring summer warming and fall cooling of the surface mixed layer (which is our main goal). In that year, buoys survived 1, 2, 4, and 10 months, generally failing owing to ice ridging or rafting. Since then, we have continued to improve the buoy design via ship-based deployments sponsored by NSF, in the hopes of re-starting our SIZRS air deployments.

Buoy data are available from our web site (http://psc.apl.washington.edu/UpTempO/Data.php) and from NSF's Arctic Data Center (https://arcticdata.io; search for UpTempO). The data are provided as Level 1 (Raw data) and Level 2 (quality control + enhanced parameters). A paper is in preparation that describes the buoy (Steele et al., 2017a). A separate paper was published that describes how UpTempO buoys can be used to validate large-scale gridded sea surface temperature (SST) data sets in seasonally open water areas of the Beaufort Sea (Castro et al., 2016). Another paper in review describes the formation of a Near-Surface Temperature Maximum (NSTM) layer during fall in the Makarov Basin (Takeda et al., 2017).

III. Scientific analysis:

SIZRS UpTempO buoys have provided fascinating data on upper ocean thermal structure. The data were used in preparation of a recent paper (Steele and Dickinson, 2016) to develop our idea of the Late Summer Transition (LST). The LST is a transition in surface mixed layer properties when a shallow, stratified, and warm mixed layer experiences enhanced wind and wave mixing in August so that surface heat is redistributed downward and sea surface temperatures (SSTs) cool even while the net surface heat flux is still downward.

SIZRS UpTempO buoy data were also used, in combination with SIZRS AxCTD and ONR MIZ DRI glider data to examine the variation of SSTs across the Marginal Ice Zone (MIZ). We find that the most popular global gridded SST data set in use today (NOAA's dOISST a.k.a. "Reynolds SST") is overly warm at higher ice concentrations (Steele et al., 2017b).

Our SIZRS grant also supported our ground-breaking work on "ice edge loitering" (Steele and Ermold, 2015). Simply put, we have for the first time investigated the daily variation in ice edge retreat speed from a pan-arctic perspective. We have found that the pace of ice edge retreat is not constant through the spring and summer: on some days it is moving quite rapidly, while during other times its northward retreat stalls, or "loiters" for periods of typically 4-12 days. Loitering happens when the wind blows ice floes southward into warm open water, where they melt, and is thus exactly analogous to the situation at the winter maximum ice edge, i.e., in the North Atlantic and North Pacific Oceans. We expect that this result will provide interesting avenues of new research on ice-edge ecosystems, on submesoscale variability and instability, and on sea ice forecasting. For example, if an ice edge has maintained its position for ~1 week, one might forecast with some accuracy that it is likely to move northward within a few days.

TRAINING

Nothing to report

DISSEMINATION

Castro, S., G. Wick, and M. Steele, Validation of satellite sea surface temperature analyses in the Beaufort Sea using UpTempO buoys, *Rem. Sens. Environ., 187, doi:10.1016/j.rse.2016.10.035,* **2016**.

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Steele, M., W. Ermold, S. Dewey, L. Rainville, et al., "SST across the Arctic summer MIZ," *J. Geophys. Res.*, *in preparation,* **2017b**.

Steele, M. and S. Dickinson, The phenology of Arctic Ocean surface warming, *J. Geophys. Res.*, *121*, *doi:10.1002/2016JC012089*, **2016**.

Steele, M. and W. Ermold, Loitering of the retreating sea ice edge in the Arctic Seas, *J. Geophys. Res.*, *doi:10.1002/2015JC011182*, **2015**.

Takeda, H., Y. Kawaguchi, M. Steele, S. Nishino, J. Inoue, K. Colburn, Quantification and characterization of turbulent heat transfer within the surface mixed layer of the Pacific-side Arctic Ocean, *J. Oceanogr., in review,* **2017**.

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13. SUPPLEMENTARY NOTES

Sea ice is retreating more in recent years, resulting in unprecedented warming of the upper Arctic Ocean. The role of this warming on sea ice retreat and advance has been explored quite recently using numerical models, but a lack of observational data limits our confidence in these results. This proposal is designed to gather data on the summer warming and fall cooling of the upper Arctic Ocean, using UpTempO (Upper Temperature of the arctic Ocean) buoys. For this project, we will for the first time build and deploy air-dropped UpTempO buoys.

In particular, we seek to determine the state of upper ocean heat at the very start of summer (early June) and then follow its evolution through the following year. This project is a contribution to the SIZRS (Seasonal Ice Zone Reconnaissance Surveys) program to be coordinated by Dr. J. Morison at the University of Washington. SIZRS will take advantage of the Alaskan Coast Guard C130 Arctic Domain Awareness flights to deploy a variety of instruments in the Seasonal Ice Zone (SIZ) of the Beaufort and Chukchi Seas. We will drop 3 buoys into leads on an ADA flight in early June, and then drop 2 more to fill in buoy network gaps late in the season on a flight in October. We will coordinate other SIZRS data programs with buoy drops and overflights through the summer and fall, in order to place our program into a larger framework.

With these data, we seek to better understand the correlation length scales of upper ocean temperature in the seasonally ice-free regions of the western Arctic Ocean, including how these correlations depend on geography and environmental conditions. We will provide our data to users such as modelers and large-scale gridded SST data producers for validation

14. ABSTRACT cont'd

activities, both in raw form, in standardized level format, and in the context of a multi-platform database we will create for this project. We will also determine statistical relationships between ice retreat/advance and ocean thermal properties in order to better understand the details of ice-albedo feedback.

15. SUBJECT TERMS

Sea ice, retreat, Arctic Ocean, UpTempO, Upper Temperature of the arctic Ocean,buoy, SIZRS, Seasonal Ice Zone Reconnaissance Surveys, sea ice prediction

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